REVISION AND FURTHER APPLICATION OF THE NELA TEST FOR COLOR BLINDNESS

BY
VERNON PHILIP SCHEIDT

A Dissertation Submitted to the Board of
University Studies of The Johns Hopkins University
in Conformity with the Requirements of the Degree
of Doctor of Philosophy
1933

Baltimore, Maryland
1936

REVISION AND FURTHER APPLICATION OF THE NELA TEST FOR COLOR BLINDNESS

BY
VERNON PHILIP SCHEIDT

A Dissertation Submitted to the Board of
University Studies of The Johns Hopkins University
in Conformity with the Requirements of the Degree
of Doctor of Philosophy
1933

Baltimore, Maryland
1936

R. UNIV.
BIBLIOTHEEK
LEIDEN

REVISION AND FURTHER APPLICATION OF THE NELA TEST FOR COLOR BLINDNESS

VERNON PHILIP SCHEIDT

CONTENTS

Introduction 1
Historical 3
Discussion of:
Blue-yellow blindness 12
Congenital total color blindness 13
Acquired color blindness 16
Inheritance of color blindness 17
Racial differences 18
Nela Test for Color Blindness 20
Problem 22
Subjects 23
Procedure 24
Results 25
Summary 42
Bibliography 43

Acknowledgments are made to Dr. Knight Dunlap for his criticism and inspiring example in scientific research; to Dr. Roy M. Dorcus for his direction and encouragement throughout this investigation; to the Departments of Psychology of Goucher College and of The Maryland College for Women for their coöperation in furnishing subjects; to Dr. E. J. Leopold for his kind permission to test patients in the Diabetic Clinic of the Johns Hopkins Hospital; and to Dr. Percival Hall, of Gallaudet College, for his permission to test deaf subjects and Dr. Joseph Morsh for his assistance in handling them.

INTRODUCTION

Anomalies of color vision have been the subject of interest and debate since Dalton's presentation of a careful analysis of his own defect to the Literary and Philosophical Society of Manchester in 1794. It is true, of course, that color-sense deficiency had been noted before Dalton's investigation but very little attention had been given it.

Color blindness became a problem of practical importance when

colored lights were used for signalling in marine and railway service. Parsons pointed out that Wilson in 1853 seems to be the first to suspect that fatal disasters had resulted to merchant ships and railway trains from mistakes made by color-blind men. Furthermore, it is known that a serious accident on a railroad in Norway, probably owing to the color blindness of the engineer, roused Holmgren's interest in the problem and gave rise to his wool test for the detection of color deficiencies. In the United States Jeffries in 1877 recognized the dangers attending color blindness and called attention to them in his publication.

With the coming of the motor-car and the adoption of the railway system of signals for the control of traffic, the problem of color vision defects was re-emphasized. In the early days of the traffic signals a great deal of trouble was caused by color-blind operators. The problem was solved, at least partially, by the adoption of red and green lights with the difference in yellow and blue values that provides cues for color-blind individuals. Some of the states (twelve of the forty-eight) adopted a variety of more or less adequate tests for color vision; whenever an applicant for a driver's license was unable to pass the tests, he was denied a license or issued one with certain restrictions. The airplane pilot also, since he must be able to see signals, has been subjected to tests of color perception.

The practical necessity of testing color vision has led to a great extent to an indiscriminate use of tests, and since none of the tests at present in vogue is fool-proof there is much confusion, increased, from the theoretical aspect, by attempts of various investigators to relate their findings to favorite theories. In the case of acquired color blindness similar disagreement exists. Although ophthalmologists recognize the importance of color defects as an index to retinal conditions, only a restricted group of them have made their data available. A recent investigation of the files of a large ophthalmological clinic showed that color defects had been noted in only five of eighty-four hundred case-histories.

The Nela Test for Color Blindness (to be described in detail later) was devised by Dunlap and worked out by Day. Haupt and others used this test, and found it adequate and practical. Although wool tests have been criticized by numerous investigators, the use of worsteds in the classification system such as is presented in the Nela Test provides a workable method for differentiation. The aim of the present investigation is the application of the test to various groups with the object of discovering which specific parts are useful in diagnosing deficiencies. It is moreover our intention to eliminate any superfluous

parts as well as to revise the test wherever necessary. Groups of individuals of different ages and groups having sensory and organic defects were tested to determine whether deficiency in color perception was in any way related to age, other sensory defects, or organic defects.

HISTORICAL

The history of color anomalies together with surveys of the various tests constructed at different periods during the development of color deficiency, has been adequately recorded by numerous investigators. Abney (1), Parsons (49), Bell (2), Collins (7), Haupt (27), and others collected the history in fairly complete form.

Bell (2) found no single statement prior to the year 1684 that showed a definite recognition of the phenomena of color blindness. The first known description of a case of color defect occurs in the records of Turberville, an oculist at Salisbury. This case is obviously not one of congenital color blindness. It is interesting to note that no further reference to this defect could be found in the literature for nearly one hundred years following. In Porterfield's *Treatise of the Eye*, published in 1759, we find a clear recognition that ". . . the motion which causes redness in me may cause the sensation of green or blue in another, or even some other new sensation which nobody has ever dreamed of."

It is generally accepted that the first case of congenital blindness recorded is that of Harris, a shoemaker, described by Huddart. Harris first suspected his defect when he was about four years old. He had found a child's stocking in the street, and in finding the owner observed that other people called it a *red* stocking. He could not understand why they gave it that color-name, since he thought it was completely described by being called a stocking. He had observed also that other children could make out cherries on a tree by some apparent difference in color, although he could distinguish them from the leaves only by the difference in shape. Since Harris had two brothers who were similarly affected, this is an early instance of the type of familial relationship that later was considered evidence for the inheritable nature of the defect.

One year later, in 1778, Scott described his own case, one of congenital and hereditary color blindness. He was unable to see green. Pink and pale blue, and full red and full green seemed alike to him. This case is of special importance because Scott's sister was also affected.

For sixteen years following the description of these cases no comments occur in the literature (Bell (2)).

In 1794 Dalton's description of his own case attracted considerable

attention. Investigation of this case brought more widely to the attention of scientists the fact that defects of color perception exist. Collins (7) and others stated that Dalton first became acquainted with his abnormality by observing a pink geranium in candlelight. Dalton reported that he could make only two or at most three distinctions of the different regions of the solar spectrum. These were yellow, blue, and possibly some purple. Parsons (50) related that Dalton was an earnest Quaker. Quakers object to bright colors; yet Dalton, having received the degree of D.S.L. at Oxford, wore the scarlet gown for several days, in happy unconsciousness of the effect he produced upon his friends. The chemist conjectured that one of the humors of his eye was a transparent but colored medium, constituted to absorb red and green rays and to transmit blue and other colors. Post-mortem examination performed at Dalton's request did not support this theory.

Two main lines of investigation have been pursued since the time of Dalton. First, the practical aspect of color defects brought about observation and collection of data; second, the theoretical phase attracted the attention of numerous investigators. For the purposes of the present problem, no attempt will be made to analyze or to discuss the theoretical aspects, but the facts that have been found will be given.

In 1812 Goethe investigated and reported two cases of persons who confused blue and pink, green and orange, and green and brown. He pointed out that the deficiency probably is incurable.

Four years later (1816) Nichols examined two cases in which mistakes typical of red-green blindness were made.

In 1837 Seebeck (60) gave a detailed analysis of several cases that he had investigated. He divided his subjects into two classes based on the difference of the length of spectrum visible to them. This later led to the introduction of von Kries's (35) classification of "deuteranopes," whose color system is reduced to blue and yellow but who have normal length of spectrum, and "protanopes," who also see blue and yellow but whose spectrum is shortened at the red end. Seebeck, Haupt (27) stated, was the first to describe a test for the detection of color blindness. The test consisted of arranging, according to resemblance, a large number of differently colored pieces of paper, glass, and wools. Silk was discarded because of its brilliancy. Seebeck was also one of the first to state that there probably is a gradual transition in degree from complete color blindness to normal chromatic sensitivity.

Wilson (73) in 1855 described a large number of cases that he studied

and tested by means of colored wools, paper, and glasses. Collins (7) stated that it was from Wilson that Holmgren got the idea for the construction of his test. Wilson pointed out also that some color-blind individuals can distinguish colors by means of other cues, such as the differences in shape and rough points. In the case of wools, certain dyes produce differences that aid in the discrimination process.

At this point the historical records are filled with arguments for and against particular theories. Pole's (52) presentation of his own case, which he satisfactorily proved to be one of red-green blindness, was a source of dispute. Maxwell had pronounced him red-blind while Holmgren, on the basis of his wool test, said he was green-blind. Pole produced evidence that not only in his own case but in numerous others color sensations were limited to blue and yellow. Von Hippel's case of unilateral color blindness also was a source of dispute, but was definitely instrumental in partially solving the problem of what some color-blind persons see. The subject was a young man, unaware of his defect, who came to Von Hippel for spectacles to cure double vision. Von Hippel introduced the case to Holmgren primarily to learn about the color perceptions of color-blind individuals. After a series of tests with Stilling's pseudo-isochromatic tables, Holmgren's wools, and Von Hippel's photometer, the investigators, although differing in opinion at first, agreed that the patient's left eye was normal and that his right eye was red-green-blind. The important fact was that the results of this investigation showed rather clearly that the affected eye saw yellow and blue, the yellow stretching over part of the spectrum usually seen as red, orange, yellow, and green, and terminating in the blue-green where there is a narrow neutral band. Blue appeared in the remainder of the spectrum.

Hayes, in 1911, according to Bell (2), supported Von Hippel's conclusions. Hayes required his subject to arrange colored papers to match what she saw in the spectroscope. She matched the complete spectrum by: (*a*) three varying shades of gray, (*b*) yellow, (*c*) greenish yellow, (*d*) greenish blue, (*e*) blue, and (*f*) violet. This matching is of course important only in the colors omitted, since it is probable that the greenish yellow paper was seen as yellow and that the greenish blue appeared as pale blue. The maternal grandfather of this case was color blind; therefore it is probable, although not certain, that the difficulty was congenital. Holmgren, Donders (10), Kirschman (32), and others reported cases of unilateral color blindness. Miles (41) found one case in an investigation of dry-goods salesmen. Unfortu-

nately, however, he did not describe it except in terms of the Ishihara Test.

Although von Kries (35) suggested the terms "deuteranope" and "protanope" to distinguish the two types of color defect exclusive of any particular theory, this differentiation was not sufficient to describe all cases showing deviations from the normal. Seebeck (60) found that most of his cases fell into two groups, but other cases seemed doubtful. Rayleigh (54), in 1881, reported experiments on individuals who had defective color vision but had normal vision in other respects, and stated that they were not equally sensitive to red and green. By equating red and green spectral light that matched a yellow light when mixed, he discovered that numerous individuals did not agree with his setting, but agreed among themselves according to the effect on them. Some, he found, required far more red than normal persons, others required an excess of green. Obviously the etiology in color vision is not a simple condition that lends itself to ready classification into two types. For the condition of lowered sensitivity von Kries (35) suggested the term *anomalous trichromates* and pointed out that individuals with this condition see the three fundamental colors of Helmholtz but have reduced sensitivity to red and green. The acceptance of this term led to a further differentiation into two groups corresponding to dichromatism. *Deuteranomalous trichromates* are below normal in sensitiveness to green; *protanomalous trichromates* are below normal in sensitiveness to red. Other classifications have been suggested by Rivers (57), Hering (28), Edridge-Green (21), and others.

Terman (65), in 1928, in an investigation of fifty-one color defectives selected by the Stilling and Ishihara tests found that in a color-sorting test in which colored papers were matched by the subjects, four stages of red-green deficiency could be recognized. The results of this investigation do not affect the accepted classification. On this point, Bell (2) has observed further that besides the variety of types of color blindness there is also a marked instability in the deficiency of many individuals. A medical student found that his color vision varied to some extent with his general health. In the case of another individual it was noted that on some days she could pass a test that on other days she failed. How much of this variability is due to physical condition and how much to psychological effects is difficult to determine. Color blindness is not an all-or-none condition but is a matter of gradation in color vision, with distribution forms strongly suggestive of the "normal" statistical form of distribution curve.

After Holmgren's development of his wool test and with the recognition of the practical necessity of distinguishing the seriously "red-green-blind" persons from those possessing normal color vision, there was a rapid development in the field of tests. The determination of what constitutes a dangerously color-blind individual varied with the numerous investigators and the tests used. Holmgren's test was accepted in almost every country as a standard for the detection of color blindness. As the investigators compared other tests, however, they found numerous cases that the Holmgren test had failed to detect. Edridge-Green (21) criticized it not only as a test-situation not comparable to everyday experience but also for composition, materials, and difficulty in obtaining duplicates of the wools employed. He argued that the relative luminosity of the colors of wools forms a distinguishing point to color-blind individuals. He pointed out also that a person with a central scotoma escapes detection when examined by this test. Since a light at a distance occupies the central portion of the field of vision, these persons recognize colors close to them but not when removed. In addition Edridge-Green stated that he could teach a red-green-blind person enough in five minutes to enable him to pass the test. On the contrary, Collins (7), Abney (1), and others found that when the Holmgren test is carefully administered the results are reliable as shown by agreement with the results of other tests.

Haupt (21) found, in a survey of the field, more than one hundred tests, most of which are merely variations of certain basic principles. In general the tests followed two lines of development. For scientific investigation various forms of spectral color-mixers, in which adequate control of purity, intensity, and saturation is possible, were developed. These instruments were, for the most part, expensive delicate devices, useful only to the trained investigator and requiring extensive test-periods for their application. For practical purposes where larger groups of individuals are tested, the time factor makes simple methods necessary. The requirements of a good test are: efficiency in the elimination of those unfit for a particular service, ease in manipulation and administration, and reliability in the hands of an untrained examiner. All the tests aimed to fulfill these requirements, but up to the present none is entirely fool-proof. Each investigator found one or more tests that failed to make correct diagnoses in some cases. For example, Preston (53) reported a case diagnosed dangerously color-blind according to Edridge-Green, who was able to pass a test on railway signals even in a fog and at some distance. This investigator

pointed out the present necessity for better means of distinguishing between those who are dangerously color-deficient and those who are not. It is obvious, since most of the tests select some of the color defectives, that either they are testing various conditions such as different portions of the retina, fovea, macula or periphery, or else other factors are operating to vitiate the results.

Haupt (27) classified the tests in her survey in the following manner:

A. Confusion tests
    1. Classification tests
    2. Pseudo-isochromatic tests
    3. Lantern tests
B. Contrast tests
    1. Flor-contrast
    2. Mirror-contrast
    3. Colored shadows
C. Pupillary reaction tests
D. Rayleigh equation tests
E. Tests using special apparatus designed to meet the requirements of practical testing
F. Spectrum tests
G. Quantitative tests
    1. Intensity
    2. Saturation
    3. Visual angle
    4. Time of stimulation
    5. Time of reaction

The group of classification tests is composed of the Holmgren test and its numerous variations. In this type the problem is to select from an assorted number of bundles of worsteds all those which approximate a given test-skein. Twenty-seven or more varieties of this method have been recorded; according to Haupt (27), Thompson, Cartwright, Schenkle, Dennet, Hoffman, Jennings, Edridge-Green, and Donders were the chief contributors.

The pseudo-isochromatic tests are, in the main, all variations of the original Stilling (62) plates. Grossman (24), Nagel (43), Oguchi (47), Ishihara (30), and Edridge-Green (22) made modifications of the original. This test consists of cards with patterns, dots or irregularly shaped spots, printed in colors on a colored background. A design, letter, or number is worked in one color against a pseudo-isochromatic background. The Stilling and Ishihara tests are at present the most popular of the group, at least in this country. Miles (42) has praised the Ishihara Test particularly as a simple and practical method of

determining color deficiencies, and has used it extensively. On the other hand Jennings (31) and Edridge-Green (23) claimed that the Ishihara Test fails to select numerous defectives that other tests pick up. Edridge-Green found that in comparing his own, the Stilling, and the Ishihara tests, of fifty cases that had been rejected by more detailed testing, only thirty-three were rejected by the isochromatic tests. Of these thirty-three subjects, nineteen failed on all three tests, fourteen passed the Ishihara Test completely, thirteen passed the Stilling Test, and all thirty-three failed on the Edridge-Green Card Test. The Ishihara Test consists of sixteen plates, thirteen of which have numbers in spots of one or more colors on a background of spots of another color. Four of the plates, nos. 6, 7, 8, and 9, are similar to the Stilling plates and cannot be read by red-green-blind individuals. In the other plates color-blind persons see a number, but a different one from that seen by the normal eye. On one plate a number is seen by color-blind persons and not by normal, while on another plate a number is barely seen by normal persons but distinctly seen by color-blind. Jennings (31) criticized the test because of the possibility of the patient's memorizing cues. When the patient sees the number 21 he must call it 74; when he sees 3 he must call it 8, etc., and because of this feature Jennings claimed that the Ishihara Test should not be used alone as a means of selecting applicants for railway, marine, or any other service in which normal color vision is necessary. The pseudo-isochromatic tests have probably produced discrepancies because they either are testing a restricted zone of the retina or are discriminating a normal from a somewhat higher color-threshold; or else they are involving factors other than color vision, such as acuity. In the present investigation a number of cases were found in which the Ishihara Test did not furnish a reliable measure of color deficiency. Furthermore, when we consider the percentages of color-blind individuals as measured by the various tests we find that in the case of the Ishihara Test used alone the usual figures vary between 7 and 8 per cent for males (Miles (42), Garth (19), Haupt (26)) while more or less adequate surveys by other methods of testing show that only 4 to 5 per cent of the males are affected.

The lantern tests, originated by Donders (11) and modified by Edridge-Green (23), Williams (72), Everbusch (16), and others, are the most popular form of test in use at the present time for the selection of marine and railway employees. The lanterns were devised to provide a test-situation that would be comparable to the natural require-

ments of marine and railway occupations. Also by means of this test it is possible to provide modifications of colors such as those occurring in rain and fog. The Edridge-Green (23) lantern, now extensively used in England by the Boards of Trade, has eight differently colored lenses and five modifying glasses, which are arranged on discs and can be turned before the opening. The modifying glasses are made to represent mist, rain, and fog of varying densities. The diaphragm of the lantern can be altered to represent a $5\frac{1}{2}$-inch railway signal at 600, 800, and 1000 yards when the test is conducted at twenty feet. The candidate must name the color presented and match the color of the light with wools, colored cards, etc.

Under the classification of contrast tests, Haupt listed those tests that resulted from the original experiments of Meyer. So-called Flor-contrast is represented by Pfluger's test in which he used black and gray numbers and letters printed on a colored background. When the test-cards are covered with tissue paper of varying thicknesses, the normal eye sees the figures through the tissue paper with the complementary color, while the color-blind eye sees nothing. Mirror-contrast has also been used as a measure of color perception. These tests depend upon the normal functioning of the color-perceiving apparatus, normal and color-defective subjects seeing different colors. Likewise, tests using the principle of colored shadows differentiate between normal and color-deficient individuals. When shadows of an opaque object are thrown on a screen in the paths of two sources of light, one colored and one white, the shadow of the colored light illuminated by the white light is brilliantly colored with the complementary of the colored light. This phenomenon was known to Leonardo da Vinci and is the principle of tests by Stilling, Cohn, Holmgren, Waldstein, and others.

Moritz Sacks in 1893 found that the action of the pupil is different in color-blind persons than in normal and explained the deviations on the basis of the changes which the lights undergo in the color-blind. Thus under certain conditions he could deduce the type of color experience from observations on the pupil. Although the methods devised by Sacks have been applied by Abelsdorft, Engelking, and Groethusen, the results have not shown the test to be very dependable for differentiation between types. It does, however, give information on complete color blindness. In a case of total color blindness investigated by Geldard (20) increased intensity of light did not modify the pupillary action.

The principle known as the Rayleigh equation, discussed earlier,

provides a method utilized by numerous investigators in the construction of tests for color vision. Nagel used the equation of red and green to match yellow as a basic principle in his anomaloscope. Hering (28), Cowdrick (8), Winfield (74), and others also constructed apparatuses on this principle.

In those tests in which special apparatuses designed to meet the requirements of practical testing are used, we have in the semaphore test devised by Black a duplicate of the actual situation presented on the railroad. His device employs semaphore figures in black on a white ground, also red and green discs, with a five-minute visual angle at twenty feet equivalent to semaphores 46 inches long at 2600 feet. The applicant must name the signal—clear, caution, or danger. Other tests in this group are the various adaptations of pocket ophthalmoscopes by Lediard (38), Scripture (59), and Nagel (44). Nagel's apparatus or Farbengleichungsapparet consists of a lamp of two metal discs with colored glasses that can be rotated in front of openings to present two contiguous fields on a black ground. Two slides allow independent variation of intensity. Objections have been raised to this apparatus on the basis that it fails to give clear diagnosis. Haupt described tests for central color vision, such as those of Fridenberg, Oliver, and Edridge-Green. In general they all use the principle of the small test-object that can be exhibited close to the eye while the subject is fixating.

Haupt (27) pointed out that for scientific purposes the spectrum tests provide the best means of analyzing color perception. Not only are the results of different investigations by this method comparable, but limits of the visible spectrum can be found together with the extent of neutral bands. The Hirschberg double spectroscope provides two spectra one above the other; the subject can be required to match one setting made by the observer's moving the other collimator. Normal subjects find a match in approximately the same wave-length while color-blind subjects vary their setting for wave-length according to the type of defect. Other modifications of this principle are found in the spectro-color-mixer of Helmholtz and the Abney combination spectro-colorimeter and spectro-color-mixer.

The quantitative tests resulted from the discovery that there exist variations from extreme color blindness to complete color perception. Donders, as Haupt (27) stated, was one of the first to attack the problem from this point of view. He found it possible to determine the ability to distinguish colors on the basis of (*a*) intensity, (*b*) saturation,

and (*c*) visual angle. Guttmann added time as a factor in quantitative measures. Intensity is tested with a sectored disc by which the threshold of chromatic perception of colored lights is obtained. Saturation may be tested with Maxwell discs that give the threshold for colors in grays. As test-objects for visual angle Donders used round pieces of colored paper together with pieces 1, 2, 3, and 5 mm. in diameter, cut from materials used for white, red, and green signal flags. Each piece was pasted on black velvet. The visual angle required to recognize the color of these test-objects can be computed either on the basis of the diameter of the test-object at a fixed distance or on the basis of the distance required to recognize the color of a test-object of fixed diameter. Snellen (64), Weber (71), Dor (13), and Landolt (36) used the visual-angle method in much the same way. Guttmann and Rosmanit used the tachistoscope in determining the difference in the amount of time required by normal and color-defective subjects to recognize the test-color. Guttmann (25) found that normal subjects required about 18 sigma for the recognition of pigment colors while color-blind subjects required 760 sigma. When spectral light was used with the tachistoscope the difference was more marked. Other devices testing color perception by means of intensity and visual angle, based on the principles previously discussed, have been set up by Parinaud (48) and Carter (4). Kolbe (34) followed Maxwell's principle in the construction of his *Farbenmesser*. This is composed of a truncated cone, covered with combinations of gray and colored pigment papers in such a way that when the cone is rotated it presents different degrees of saturation. Through a slit in a black screen, the subject is asked to indicate the point at which he can just see color. The color is then identified with samples. Other methods of saturation determinations based on the principle of combining pigment and fluids were reported by Bull and Fere.

A new edition of Ferree and Rand's (17) instrument for testing the light and color sense has been recently described. Its utility is mainly in detecting central scotoma for light, but by inserting the necessary filters it can be used for detecting color vision.

Blue-yellow blindness

Although congenital blue-yellow blindness, called *tritanopia* by Parsons (49), is not definitely established, a few cases have been reported. Collins (7) pointed out that it is generally considered pathological, usually accompanying definite changes in the retina. Parsons

(49) quoted a case reported by Vintschgau and Hering that was claimed to be congenital. This case, however, also showed changes in the red and green, thus approximating total color blindness. There was a neutral band in the yellow but the violet end also appeared colorless. Yellow and blue could be matched with gray but a match could not be made between red and green. Abney and Hess reported cases of this defect in which the pigmentation of the macula was unusually dense. Richardson (56) reported a case in which the subject saw blue as a dazzling white. Abney (1) found one case which he termed a genuine violet-blind, on the basis of the Young-Helmholtz theory. This individual had an interesting nomenclature for colors that adequately checked with the luminosity tests made. The only two colors that the subject saw were red and black. He named all greens and blues as black, the distinction between the two being that the former was "bright black" and the latter "dark black." Hering (29), Konig (33), Stilling (61), and Donders (12) reported similar cases. Scarlett recently reported, in an article discussing senile macular changes of the retina associated with focal infection, a case in which there was a central scotoma for blue, probably as a result of retinal arteriosclerosis.

Parsons (49) stated that "tritanopia" appears to be commonest in cases of detachment of the retina and that it is stimulated in cases of jaundice and sclerosis of the crystalline lens, these being due to absorption by yellow pigment. Soriano (63) pointed out that blue-yellow blindness probably indicates a lesion of the sensory epithelium of the retina.

From the variety and small number of cases of blue-yellow blindness reported it is obvious that this condition is extremely rare, almost invariably associated with pathological conditions, and may be due to selective absorption by ocular media. It has been pointed out that since this defect causes little risk of confusion of red and green lights it is not considered of much practical importance and therefore has not been investigated to the extent of red-green blindness.

Congenital total color blindness

Monochromatic vision, or total color blindness, is admitted by most authorities in this field to be a rare condition. Bell (2), in a detailed examination of the literature, found only one hundred and nineteen cases published during the preceding one hundred and forty-seven years. Chance (5), reviewing the field a little later, placed the number of cases at one hundred and thirty. Geldard (20) recently considered the num-

ber to be approximately one hundred and twenty-five cases; he added one that he examined. In the United States only twelve cases have been reported. Vogt (67) pointed out that the scarcity may be more apparent than real, since he found three cases during the examination of four thousand school children. He suggested that many have been overlooked because, since poor vision is the primary complaint, oculists may not have tested for color sensitivity.

Hypothetically, the common feature of congenital total color blindness is that colors are differentiated by their light and shade only, black and white are recognized and differentiated and all other colors are represented as gray, the tint varying with the hue and brightness. Colored pictures are to totally color-blind individuals indistinguishable from steel engravings, and the solar spectrum appears to them as a streak of light of graduated intensity frequently described as "brightest in the middle." Chance (5), Bell (2), Parsons (49), and others agree that associated with total color blindness are usually found such symptoms as (*a*) amblyopia, (*b*) photophobia, and (*c*) nystagmus. The nystagmus, however, is not the true type, the movements in the two directions being of the same sort. Some investigators have also found a shortening of the red end of the visible spectrum, displacement of the brightest part of the spectrum from the yellow towards the green and sometimes a central scotoma in the fields of vision. Fry (18) reported the case of a woman, aged twenty-three, who submitted to examination because of day-blindness. She was amblyopic and had a short lateral "nystagmus." Ophthalmoscopic examination revealed no lesion of the vessels, macula, choroid, or retina. The luminosity curve of this patient showed that the point of maximum brightness was displaced towards the green, and the red end of the spectrum was shortened. Geldard's case had the usual amblyopia, photophobia, and nystagmus. An interesting symptom not mentioned in some of the other cases of total color blindness was found in the pupil reaction of this subject. There was almost total lack of response to increased intensity of light.

These cases like other types of color blindness are not always clear-cut in their total deficiency. Bell, Grunert, and Nettleship believed that some cases of alleged total color blindness probably see slight color. Bell (2) reported a case by Becker that is interesting because it is one of only two recorded cases of unilateral total color blindness that cannot be definitely attributed to pathological processes. A family history of color blindness, although of unknown type and extent, was

believed substantiation of the congenital nature of the abnormality. This patient was able to recognize brown; there were no attendant photophobia, nystagmus, or other defects. Possibly the case should not be listed among the congenitally color-blind; however, it suggests that there are gradations in total color blindness just as there are gradations in the other types.

Chance (5) maintained that because of the "nystagmus" found in most cases, ophthalmoscopic examination has been difficult if not impossible. Bell (2), however, quoted some cases in which examination revealed signs of pathological change in the region of the fovea with yellowish red patches in the macula region. Other investigations by Woofflin (70) and Waardenburg (69) demonstrate that the yellow color is absent from the macula. In one case the oval macular reflex could not be elicited.

A condition similar to total color blindness has been found in cases of albinism. Visual defects such as amblyopia, photophobia, and nystagmus have been shown by Nettleship (49), Bell (2), Usher (66), and others to be characteristic of albinism as well as of total color blindness. The visible spectrum is of normal length, however, in most albinos. Usher (66), who has investigated this phase carefully, reported that he found only a few cases of color defect in albinos; he added that the color vision of albinos has not been adequately studied.

In reviewing the literature concerning anatomical changes in the eye of totally color-blind individuals, we find but two investigations quoted. Bell (2) discussed an investigation by Pergens of a case of acquired color blindness following a serious illness. Microscopic examination of the eyes after death revealed no signs of degeneration of the retina or difference in the arrangement and condition of the cones. Pergens concluded that color vision had been eliminated by some central lesion as a result of the disease. The second microscopic examination was made by Larsen (37) on the eyes of a suspected case of congenital total color blindness. Although the right eye was imperfectly fixed and postmortem degenerative changes had occurred, Larsen was able to show that the cones and rods were present in their usual number. The left eye was more successfully prepared and a section through the fovea showed that the cones of this region were short and plump while in the normal eye they are long and slender. Surrounding the fovea was a region characterized by short thick cones, and in between these were a series of shorter rods. A little distance from the center, the retinal structures appeared to be wholly normal.

One point at least was ascertained. In this totally color-blind eye there were no fewer cones than in the normal eye. Bell (2) concluded that in this case there was evidently a developmental defect of the fovea and macular regions, but in the absence of clinical history it is difficult to draw definite conclusions. The primary step towards a solution of the problem of total color blindness is in the direction of further histological studies both of the eyes and of the brains of affected persons.

Acquired color blindness

Acquired color blindness may be classified as partial and total. This defect is interesting in that the individual has had normal color vision but because of disease in the eye or brain, or other malfunctioning, or perhaps because of progressive developments of an inherited tendency, his perception of colors has been reduced or eliminated.

In considering partial color blindness we find that various toxic conditions cause impairment of color vision. Sometimes the perception of red and green is affected; sometimes central scotoma for blue is produced. Parsons (51) stated that tobacco, alcohol, quinine, and other poisons produce changes in color perception. A toxic condition produced by tobacco usually augmented by alcohol has been claimed to cause a central scotoma for red and green. In some cases the scotoma is small, horizontally oval between the fixation and blind spots; in other cases it extends to the limits of the red field. Retinal changes in this condition are very slight, and if the toxic agents are discontinued the prognosis is good. It is assumed further that the defect is probably due to poisoning of the ganglion cells of the retina. Since the ganglion cells of the fovea and macular region are the most highly differentiated, perhaps they suffer first and most severely in any toxic condition. Amblyopia produced by diabetes, carbon disulphide and iodoform resembles that alleged to be produced by tobacco. Diabetics appear to be especially susceptible to tobacco.

Scarlett (58) found, in a review of the literature concerned with senile macular changes, that numerous investigators point out defects in color vision due to macular changes that may be associated with focal infection. Finlay, he reported, found a macular condition that he thought was due to intestinal stasis, caused by a dilated colon, since treatment of the latter condition improved the vision and cleared up the macular inflammation. Scarlett pointed out further that a central scotoma area deficient for color is usually an early sign of alteration that may be in the macular region.

Parsons claimed that numerous conditions of the retina such as

detached retina or choroiditis affect most markedly the perception of the blue end of the spectrum. He found also that in sclerosing lenses there is an increase in the amber pigment in the nucleus of the lens, which cuts down the perception of color by absorption.

Collins (7) discussed an interesting case investigated by Kollner. The progressive steps from normal color vision to complete color defect were observed. Kollner found two stages: in the first, yellow and red were distinguished while yellow and green were confused; in the second, all the colors from red to the neutral band in the blue-green were confused, and distinguished only by differences in brightness.

Bell (2) described the case of a woman, aged thirty-five, in the sixth month of her first pregnancy, who had serious symptoms such as albuminuria, generalized edema, pericardial effusion, orthopnea and headaches; she became totally blind, and immediate induction of labor was imperative. She was then totally blind for three weeks and absolutely color-blind for three months. As her vision returned, white and black were first distinguished. Approximately three months later blue tints began to appear, then yellow, brown and red, and finally green. After five years her color sense was entirely normal.

Acquired total color blindness has been found in numerous cases to be a progressive step, occurring after partial color blindness and caused by the diseases, toxins, and conditions discussed above. Cases of optic atrophy, Bell (2) stated, show disabilities of vision almost invariably associated with restricted color sense. The color vision may be entirely abolished long before vision for form is lost. Edridge-Green (21) has described a case of color blindness resulting, as far as could be determined, from overtaxing the eyes. The individual was a sea captain who habitually embroidered in his spare time. One afternoon he prolonged his work until twilight and found it difficult to select suitable colors from his yarns. To obtain more light he went into the companion and continued his needlework, and while thus taxing his eyes his ability to distinguish colors suddenly disappeared. Tests subsequently demonstrated that he was almost completely color-blind.

Other cases of complete acquired color blindness have been described in the literature by Lenz (39), Mackay (40), Dunlop (15), Bell (2), and Parsons (49).

Inheritance of color blindness

Nettleship's collection of pedigrees (46) shows that the condition of congenital partial color blindness indicates a hereditary factor, and further that it apparently belongs to that group of inheritable condi-

tions that are chiefly manifested in males and transmitted through their unaffected daughters but not through themselves directly to their sons. The condition, however, is not invariable and does not appear to conform at all rigidly to the laws of sex-limited hereditary defects.

Collins (7) found evidence to support the theory known as Horner's Law (based on cases of transmission traced by Horner of Zurich).

Horner's general conclusions are: (*a*) That color-blind fathers have normal-eyed sons. (*b*) That color-blind sons have normal-eyed fathers. (*c*) That sons of daughters whose fathers are color-blind are most likely to be color-blind, although not without exception; that is, color blindness is transmitted from grandfather to grandchild.

Downey (14) recently reported a study of three generations of one family in which seven members were color-blind, one female and six males. In general the inheritance is in accordance with Mendelian expectation, except that it is sex-linked, recessive in women and dominant in men. Wallen (68) and Brunner (3) also noted in the studies of families that the inheritance is sex-linked and usually ascribed to the X chromosome. Sacks (57a) in an investigation of several generations of one family found that red-green blindness was always recessively sex-bound.

In the case of total color blindness very little evidence has been found to show that this defect can be definitely attributed to inheritance. Among Nettleship's pedigrees (46), although the evidence is still meager, in no case was the condition found in more than one generation, while in only one case was there a sib with the same defect. Since numerous cases of color blindness occur in mother and daughter, it is clearly indicated that no simple Mendelian rule of inheritance and no rule of sex-heritage is possible. On the other hand, the variety of cases of acquired color blindness and the cases in which color blindness of the apparently congenital type does not appear until after childhood suggest that a factor inherited is a metabolic tendency, perhaps glandular, that causes color blindness but that may not produce color blindness in any particular degree.

Racial differences

Although the existence of racial differences in color perception is still an unsettled point, there is some evidence, quoted by Parsons (49), Bell (2), Rivers (57), Garth (19), Clements (6), and others. Bell states that the condition is supposed to be especially prevalent among Jews and quotes the following figures:

	Males		Females	
	Number examined	*Per cent*	*Number examined*	*Per cent*
General population	14,846	3.5	489	0.4
Jews	949	4.9	730	3.1

It is admitted that the difference is unreliable, that the methods of testing and the conditions of testing have been so varied that slight value can be placed on the results, and that "Jews" are no more a "race" than are Presbyterians. Rivers (57) investigated so-called "primitive" races such as the Todas and the Papuans of the Torres Straits and found that among those Papuans examined red-green blindness did not occur, while among the Todas it reaches the highest frequency recorded for any community. Rivers made further observations on the color fields of these two groups and found that while in the Papuans the color fields were of considerable size, the Todas' were very restricted. In only one man did the field for blue seem larger than those for other colors. The tests in the main were carried out by means of Holmgren's wools, and in view of the questionable nature of this method the results may not be entirely reliable. The number of Todas tested was 503; 43 were definitely color-blind.

Garth (19) and co-workers recently reported an investigation, in which the Ishihara Test was used, of Indians at Sante Fe and Albuquerque, New Mexico, Holy Rosary and St. Francis Missions in South Dakota, Haskell Institute at Lawrence, Kansas, and at various points in Colorado and New Mexico, where Utes, Apaches, and Navajo were tested. They reported other investigations in which they tested Mexicans, the native-born (Spanish-Americans), immigrant Mexicans, in Colorado, and natives of Old Mexico in Mexico City. Three groups of Negroes were investigated, in Tennessee, in North Carolina and in Colorado. Groups of unselected Gentiles and Jews were tested in and around Denver. Although the tests were carried out for each eye individually no case of monocular color blindness was discovered. The results are given in table 1. The data quoted show that on the basis of the Ishihara Test the unselected white males show a higher percentage of color blindness than any other racial groups; nevertheless, Garth is not disposed to call this a racial difference but thinks it may be due to some selective factor.

Another investigation of full-blooded Indians, mixed bloods and northern Negroes from Connecticut undertaken by Clements (6) showed 2.0 per cent for the full-blooded Indians, 1.2 per cent for the mixed

bloods and 3.4 per cent for the Negroes. These figures are for males only.

From the existent data on racial differences in color vision it is impossible to draw any valid conclusions. Until standard methods are adopted and adequate tests found, comparisons of groups variously selected cannot be carried out.

TABLE 1

Results of the Ishihara Test on various racial groups

(After Garth (19))

RACIAL GROUP	MALES			FEMALES		
	Number tested	Color-blind		Number tested	Color-blind	
		Number	Per cent		Number	Per cent
Whites, unselected	795	67	8.4	232	3	1.3
Whites, Jews	200	8	4.0	175	0	0
Indians, full-blooded, various tribes	562	14	2.5	337	0	0
Indians, full-blooded, Navajo	535	6	1.1	456	3	0.7
Indians, mixed-blood	480	25	5.2	523	4	0.8
Mexicans, in Old Mexico	571	13	2.3	494	3	0.6
Mexicans, immigrants	523	13	2.5	469	4	0.9
Spanish Americans	346	13	3.8	390	3	0.8
Negroes, southern	538	21	3.9	390	3	0.8
Negroes, northern	254	7	2.8	165	0	0

THE NELA TEST FOR COLOR BLINDNESS

The Nela Test is a wool test of the classification type composed of two parts, test I having twenty-four triplets, and test II twenty-three. Each triplet is made up of three bundles of worsted of different hues placed side by side on a black cloth. The particular color combinations represented by these triplets were selected on a basis of actual confusion made by color-blind persons. The test is named for the Nela Research Laboratory where it was originally devised by Dunlap. Day in 1922–1923 worked out other color combinations under controlled laboratory conditions and added them to the test. The Nela Test, as it was used by Haupt, was composed only of test I; test II, however, is not fundamentally different from test I except that it embodies more variations of some of the basic confusions represented in the first section.

In each triplet two of the three skeins, the middle and one of the out-

TABLE 2

Hues of the skeins used in the Nela Test for Color Blindness

TRIPLET	HUES					
			Test I			
1	Green	10	Green	6	Brown	4a
2	Red	1	Brown	6	Brown	7
3	Brown	4a	Green	7	Blue-green	6
4	Yellow	6	Green	6	Pink	1
5	Green	6	Brown	4a	Orange	3
6	Brown	5	Brown	7	Red	8
7	Brown	7	Blue	13	Violet	2
8	Blue	13	Pink	1	Rose	1
9	Brown	7	Green	10	Green	6
10	Rose	3	Blue	4	Violet	5
11	Gray	1	Blue-green	6	Green	11
12	Red	8	Blue	13	Blue	4
13	Green	8	Brown	4a	Brown	3
14	Blue	13	Blue	12	Pink	2
15	Blue	4	Blue	12	Violet-red	5
16	Violet-red	5	Pink	5	Violet	2
17	Blue	12	Pink	2	Red	1
18	Rose	5	Violet-red	5	Blue	4
19	Red	1	Brown	1	Brown	2
20	Red	5	Brown	5	Brown	1
21	Green	1	Green	9	Brown	4a
22	Red	9	Red	7	Brown	4a
23	Red	9	Red	7	Blue	6
24	Rose	1	Rose	3	Blue	12
			Test II			
1	Red	7	Green	6	Blue-green	1
2	Blue-green	6	Green	2	Brown	9
3	Blue	15	Blue	6	Pink	2
4	Green	7	Green	9	Brown	8
5	Green	7	Red-brown	2	Red	1
6	Red-brown	1	Red	1	Brown	1
7	Gray	2	Rose	4	Red	1
8	Gray	6	Rose	2	Rose	1
9	Gray	2	Blue-green	3	Green	10
10	Gray	9	Blue	7	Blue	1
11	Black		Green	11	Green	6
12	Gray	3	Blue-green	6	Green	1
13	Gray		Violet-red	6	Pink	3
14	Violet-red	1	Blue-green	1	Green	6
15	Brown	1	Green	11	Green	7
16	Yellow	5	Brown	10	Green	4
17	Black		Pink	3	Violet-red	6
18	Green	11	Red	1	Red	7
19	Black		Blue	13	Blue	7
20	Violet-red	6	Violet-red	5	Blue	
21	Blue	12	Pink	2	Red	
22	Blue-green	7	Green	6	Brown	10
23	Brown	1	Blue		Blue	13

side bundles on the right or on the left, are the same or somewhat similar in hue. Each skein is about 3 inches long and 1 inch wide. The subject must select the skein, on the right or on the left, that more closely resembles the middle one in hue. Since no color-naming is required it is possible to include mixed hues that are highly diagnostic of defect but that are difficult for the average person to name. The problem is fairly simple and was easily mastered by the majority of the groups examined.

Table 2 gives a list of the hues of the different worsteds used in both tests. Although the saturation and brightness values cannot be given for the various colors, the table does provide some cue to these differences by the file number given after the hue for each skein of each triplet. It will be noted later in the discussion of the data that a large number of errors were made on the triplets in which the brightness of the two skeins, not exactly similar in hue, was approximately equal. The factor of brightness plays a rôle in the decisions of some of the persons of normal vision, although the subjects are warned against making judgments on such a basis. The color-weak and color-blind persons invariably make errors when they resort to brightness alone as a basis for decision.

Although a numerical score can be taken as a standard for passing or failing on the Nela Test, a more important feature is the type of error made, together with successive errors on similarly diagnostic triplets. Since the test includes many variations of the usual confusions made by color-blind and color-weak individuals, we can rather easily diagnose the type of color deficiency from an analysis of the errors made by the subject. In some cases in which subsequent error is caused by a previous difficult decision, retest shows whether the error is a true one or not.

The Ishihara Test was given in conjunction with the Nela Test as a check of central vision.

Problem

This investigation was undertaken primarily to discover the effective triplets in the Nela Test, in order to lay the foundation for a revision. It was proposed also to apply the test more widely in order to collect data on different types of individuals. The latter was done to discover not only the type of error made but also any limitations of this particular type of test-situation. The problem of application of this type of test to deaf subjects with whom communication for the most part is reduced to a system of signs was also investigated. Another point of interest that led us to test deaf persons was the collection of data concerning the incidence of color blindness associated with other sensory defects. To

investigate the test further and also to clear up some problems of acquired color blindness a group of patients variously affected by diabetes, including diabetic retinitis, was studied.

Subjects

The subjects of this investigation may be divided into four groups. Group A includes young men and young women, mostly college students, ranging in age from 18 to 30 years; group B includes men and women ranging in age from 65 to 83. The ages of the older group can only be approximated since numerous individuals admitted that they were over sixty-five but would not disclose their exact age. In group C we have a sampling of deaf young men and young women. This group was composed entirely of students at Gallaudet College and Kendall School of the Columbia Institute for the Deaf, in Washington. Approximately 30 per cent of both the females and males of the deaf group were congenitally deaf while the remainder are reported to have lost their hearing through diseases in childhood, such as meningitis, measles, scarlet fever, and infantile paralysis. If congenital deafness is a hereditary factor, it may be supposed that defects of other sensory mechanisms also obtain. Bell quoted data, collected by the British Ophthalmological Society, which tend to show a higher incidence of color defect among the deaf than among the general population. She does not state, however, the tests used or the procedure involved, which are of extreme importance in this case.

Group D is composed of diabetic patients examined in the Clinic of the Johns Hopkins Hospital. The various cases included in this group will be treated more or less individually in the discussion of the results, and since their reactions are not entirely based upon defective color vision, the data will not be included in the tables showing the types of error made by the other groups.

Below are listed the number of persons in each of the groups tested:

Group A	Men	267
	Women	243
Group B	Men	101
	Women	85
Group C Deaf	Men	66
	Women	60
Group D	Men	18
	Women	15

Procedure

In groups A and B each eye was tested individually, first on the Ishihara Test and then on the Nela Test. Since in all cases test I of the Nela was used first, the testing of the alternate eye on the Ishihara was interposed between test I and test II. No attempt was made to start with the same eye but rather the choice of eye was alternated from subject to subject. The Ishihara Test was given as the manual directs. Each plate was read at a distance of less than 30 inches. Although the manual advises the omission of plates 12 and 13, except in subjects shown to be color-blind by the earlier plates, the full sixteen plates were used.

The subject was seated before the test-table; he was instructed to indicate for each triplet on the Nela Test whether the middle skein agreed more closely in hue with the skein to the right or with the skein to the left. Further, he was cautioned to decide on the basis of color or hue alone and not on brightness.

Instructions for the deaf subjects, by necessity, were slightly different. In the use of the Ishihara Test the instructions were given by pantomine. The first plate with a number, seen alike by color-blind and normal persons, was exhibited and motions were made to indicate that the subject was to write the number down. This method although seemingly crude accomplished the purpose very satisfactorily. The majority of the college students included in this deaf group were so capable at lip-reading that instructions could be conveyed in the usual fashion. In giving the directions for the Nela Test the subject was made to look at a sample triplet, then the examiner indicated by means of signs that the middle skein and one of the outside skeins were somewhat similar while the middle skein and the other skein were not. The subject was then tried on another triplet to see if he had grasped the problem. If so, we proceeded with the test, using each eye individually as in the other groups. In cases in which the problem was not understood readily, more detailed instructions were spelled out in sign language by Dr. Joseph Morsh, of Gallaudet College, who assisted in testing this group.

In dealing with group D, the diabetics, the test procedure outlined for groups A and B was followed except in some cases in which it was found necessary to test both eyes together rather than individually. With this group retests were made at odd intervals whenever the patients were available at the Clinic. In this part of the investigation we were interested not only in color deficiencies caused by diabetic retinitis but also in the changes in color vision relative to the condition of the individual.

Results

Table 3 presents the data for the right eye of the young men in group A. The extreme right-hand column gives the total number of cases making no errors, one error, two errors, etc. In those cases making one error, the errors are spread over triplets 1, 2, 4, 14, 16, 17, and 18. Errors on these triplets may be due entirely to the subject's allowing brightness to be a guiding factor; however, if we trace down the columns under these triplets we see that errors in some of them persist through the color-blind cases. In those cases making two errors, the same

TABLE 3

Distribution of errors on the Nela Test for college men. Test I. Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									138
1	11	2		5										10		2	19	6							46
2	14	2		4	4									12		6	18	2				4			33
3	12	4	5	8										11		2	16		6			2			22
4	4	2	3	4	1						3			9			10		6			2			11
5	2				6				5	2	4			4	4		5		2	1					7
6	1				1				1						1				1		1				1
7	1	2	2		2	1					2				1		1		1			1			2
8		1	1	1		1			1		1				1				1						1
9	1	1	1	1	1						1			1	1							1			1
10	1	1	1	1					1		1			1	1				1		1				1
11		1	1	1	1	1					1		1	1	1				1	1					1
12	1	1		1	1				1			1	1	1	1		1		1		1				1
13																									0
14	2	2	2	2		2			2	1	2			2	2		2	1	2		2	2			2
Total....	50	19	16	28	17	5			11	3	15	1	2	52	13	10	72	9	22	2	5	12			

triplets noted above persist, but there is a noticeable tendency for errors in other triplets. The added triplets for this group are confusion types that seem to give the color-blind individuals trouble. Thus we may suspect that some of the cases in which two errors are made may be found on more adequate examination to be color-weak. The cases making three errors extend their type of error to other triplets. Reference to the hues involved in these combinations shows that in general some of the confusions represented here are typical confusions of the color-weak. It may be noted for the purpose of later elimination of the inactive parts of this test that no errors are made on triplets 7, 8, 23, and 24, while on

triplets 10, 12, 13, and 20, three, one, two, and two errors respectively are made.

Tentatively we may classify those cases making more than four errors as "color-blind." Although the application of this standard gives a slightly high percentage of color-blind cases it must be remembered that the important point in this test is not so much the number of errors made as the types of errors and whether or not the individual is consistent to some extent in his particular confusions. This tentative standard, although it includes a number of individuals who might be

TABLE 4

Distribution of errors on the Nela Test for college men. Test I. Left eye

NUMBER OF ERRORS	TRIPLETS																						TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									138
1	9	2	1	6		2								11	1	1	9	4			1				47
2	12	1		5	4									11		4	14	2	2			3			29
3	15	3		6	2									14		1	9		1			1			26
4	7	2	4	3	4						2			9	1		7					1			10
5	3		2						4		5			3	2		2		3		1				5
6	1				1						1						1		1						1
7	1	1			1						1				1	1	1								1
8		2	3	3	2	1			1		3				2	1	2	1	1		1	1			3
9																									0
10		1	1		1				1		1			1			1		1		1	1			1
11																									
12	1	2	2	2	2	1			1		1		2	1	2		2		2	1	2				2
13																									
14	2	2	2	2		2			2	1	2			2	2		2	1	2		2	2			2
Total...	51	16	15	27	17	6			9	1	16		2	52	11	8	50	8	13	1	8	9			

designated as "color-weak" rather than "color-blind," certainly weak in color perception, includes all of the more typically defective in color vision.

Table 4 presents the data for the left eye of the young men in group A. A comparison of the right and left eyes shows that the general trend of errors is the same with the exception of two subjects who made errors on triplet 6 for the left eye but not for the right. Ten combinations eliciting relatively few errors remain the same for the left eye as for the right.

The results for the right eye on test II are given in table 5. In cases in which one error was made, the approximately equal brightness of the center and the wrong skein seems to be a guiding principle. Triplets 10 and 22 present particular combinations that seem to produce error. It will be noted, however, that these triplets not only cause errors for the subjects making few wrong choices but also for the definitely color-blind subjects. In the case of triplet 16, in which we have yellow, brown, and green skeins, the mistakes persisted throughout the various error groups. It seems obvious, from a consideration of the types of errors made in

TABLE 5

Distribution of errors on the Nela Test for college men. Test II. Right eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								138
1			4	2		8	5			10	2		1			8					1	7		48
2	5	4	6			11	8			14	5					6				3	4	10		38
3	4	2	3	7		8	5			14	3					7				2	3	8		21
4			2	6	2	4	1			8	2		3			6	2				2	6		11
5			2	3	1	3	2			4			1			3					2	4		5
6																								
7	1	1							1	1		1	1			1								1
8																								
9	1	1			1	1	1			1						1			1	1		1		1
10		1					1					1	1		1	1	1	1			1	1		1
11																								
12	1	1		1		1	1	1		1			1	1	1	1						1		1
13	2	2		2	1	2	2	2		1		1	2	2	1	2		1			1	2		2
Total...	14	12	17	21	5	38	26	3	1	54	12	3	10	3	3	36	3	2	1	6	14	40		

the cases of the groups making one or two mistakes, that these errors may be attributed either to actual weakness of the color sense or to the subjects' failure to understand the problem of distinguishing hues and disregarding brightness. It is not likely that the errors are entirely due to a misunderstanding of the problem, because not all the triplets in which brightnesses are approximately equal were misjudged. For eight triplets there were three or less errors made. At least some of these triplets on which few errors were made could be removed from the test. Some of them undoubtedly have utility for certain subjects, as

will be seen in dealing with the other groups, and therefore should be retained.

Table 6 presents the data for the left eye of the young men. Agreement between eyes in most cases is fairly constant, with an occasional variation.

The results of the Ishihara Test, given for the various groups in table 19, do not show any exact agreement with those of the Nela Test. A number of cases have been found that would be diagnosed color-blind by the Ishihara Test that made few if any errors on the Nela Test. The

TABLE 6

Distribution of errors on the Nela Test for college men. Test II. Left eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								137
1		2	5	4		3	2			14						7					3	8		48
2		3	8	7		5	6			16	4					19	2		1		6	12		40
3	3	2	1	8	1	8				11				2	3	8	1		1		1	10		20
4	1	2	1	2		4	1			8	1		2			4	2			2	4	6		10
5		3	2	6			3			4	2	2	3			1	1					3		6
6		1	1							1		1	1			1								1
7																								
8																								
9																								
10	1	2			1	1	2			1		1	1		1	2	2	1			2	2		2
11																								
12	2	1		2	1	2	2	1		1			1	1	1	1		1						2
13	1	1	1	1		1	1	1		1			1	1	1	1						1		1
Total...	8	17	19	30	3	24	17	2		57	7	4	9	4	6	44	8	2	2	2	16	42		

fact that pseudo-isochromatic tests do not check with other tests has been noted in an earlier discussion. Still other cases are found in which the type of error in the Nela Test indicates deficiency in color perception but in which the Ishihara Test shows normal color vision. These differences indicate that the two tests are not testing exactly the same color function. The cases included in table 19 are all those making more than one error, that error occurring on the fifth plate. It was necessary to eliminate the fifth plate because of a number of subjects who not only could read what was there for the normal but could also see the number for the color-blind.

The data for the young women in group A is assembled in tables 7 and 8. In comparing the types of errors made by this group with the types made by the men we find there is a marked tendency in the women to make more errors on triplet 1, test I, than in the men, at least in the case

TABLE 7

Distribution of errors on the Nela Test of college women. Test I

Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									137
1	22	3		2	3		1							6	1	3	13		1						54
2	13	4		1	8		1							9	7	8	19								30
3	7			2			1							6	5	8	8		1						10
4	4	3						1		1		1		3	3		4		2						5
5	2				1	2									2		1		2						2
6	1		1		2				2						2				2		2				2
8	1	1	1		1		1										1	1	1		1				1
11	1	1		1	1				1					1	1	1	1	1			1				1
Total...	51	12	2	6	16	2	4	1	3	1		1		25	21	20	47	2	9		4				

Left eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	2																								130
1	26	6		2										7	3	2	10								58
2	22	10		3	5		1							12	3	1	11		3			1			36
3	10				7			1		1		1		5	2	3	4		1		1				12
4	3				2	2								4		3	2								4
5	1	1			1				1						1										1
6	1				1	1								1					1		1				1
7	1	1	1		1		1							1	1										1
Total...	64	18	1	5	17	3	2	1	1	1		1		30	10	9	27		5		2	1			

of those making only one or two errors. In both tests I and II the triplets on which most of the errors were made, by those making one or two mistakes, are combinations in which brightness plays a large part.

Tables 9 and 10 show the results for the men in group B. Although a slightly higher percentage of color defect in this older group might have

been expected, because of the greater chance of disease or other progressive changes affecting color perception, no such conclusion could be drawn. Examination of the non-diagnostic triplets for this group discloses that for test I with the right eye, twelve triplets show one or no errors. The results for the left eye are similar to those for the other

TABLE 8

Distribution of errors on the Nela Test for college women. Test II

Right eye

NUMBER OF ERRORS	TRIPLETS																						TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								130
1			6	1		8	7			12						1	2				2	15		54
2	1	1	8	4		6	6			19	1		1			2			5		6	14		37
3			4			4				8	2	2				1			3			10		14
4				1		2	3			3						1			1	1	1	3		4
5				1		1	1			2	1		1			1			1			1		2
6		2		1		2	1			2						1			1	1	1	1		2
Total...	1	3	18	8		23	18			46	4	2	2			7	2		11	2	10	44		

Left eye

NUMBER OF ERRORS	TRIPLETS																						TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								132
1		1	6	1		12	6			12					2						1	10		51
2			7	8		3	6			18	2		1				3			2	4	16		35
3			6	3		4	8			11	1		1			4			3			10		17
4	1		3	1		1	3			4						1			2			4		5
5	1			1		2				2						1			1			2		2
6				1		1				1	1		1						1					1
Total...	2	1	22	15		23	23			48	4		3		2	6	3		7	2	5	42		

groups of males. For test II there are perhaps triplets that are ineffective for diagnosis for the aged men.

One difference observed in the aged women and not in the younger women is a tendency to misjudge combinations in which the worsteds are highly saturated; this is indicated in tables 11 and 12. Triplets 2, 7, and 19 of test I also show this to some extent. On the other hand, throughout the testing of these individuals, whenever judgment was

required on a triplet in which one of the skeins was particularly dark (i.e., the color very low in saturation), the subjects would say that it was "colorless," "just dark," or "black." On numerous occasions in which the subjects thought aloud, this fact was demonstrated even though the

TABLE 9

Distribution of errors on the Nela Test for old men. Test I

Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									53
1	5	2		4										4	1		3		1						21
2	6	1	1	5										3	2	1	4		1						12
3	4	2		3	1									2			3								5
4	4	3		2	1									2		1	2		1						4
5																									
6	1			1	1						1				1						1				1
11	2	1	2	1	2						1		1	2	2	2	2		1	1	2				2
12	2	2	1	2	1	1			1	1	2			2	1	1	2		2		2	1			2
Total...	24	11	4	18	6	1			1	1	4		1	15	7	5	16		6	1	5	1			

Left eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									56
1	6	3		4										3		1	2								19
2	5	2	1	3									2	4			5	3	2			1			14
3	1	1	1	2										1		1	3		2						4
4		1	1		1									3	1		2		2			1			3
5																									
6																									
11	2	1	1	2	2				2		2			2		1	2		2		2	1			2
12	2	2	2	2	1				1	1	2		1	1	1	1	2		2		1	2			2
Total...	16	10	6	13	4				3	1	4		3	14	2	4	16	3	10		3	5			

judgment was in keeping with the requirements of the test. This occurs, for example, in the case of triplet 3, test I, in which we have brown, dark blue, and dark violet skeins. Some subjects saw the blue as black but recognized both the brown and violet. In such cases, however, the dark blue skein was usually classed with the violet. The

supposition was made that while the center skein and the brown are distinctly not similar, the center skein and the violet may have some relationship. Triplet 19, Test II, presented another case in which dark blue was judged as black. This is a combination of black, dark blue,

TABLE 10

Distribution of errors on the Nela Test of old men. Test II

Right eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								58
1			1			2	1			7	1		1			4			1			3		21
2	1		3	2		2	5			6	2					3								12
3			2	1		1	1			3						1			1			2		4
4				1		1	1			1														1
5				1		1				1						1						1		1
6																								
11	1	1		1		1	1			1	1		1		1	1						1		1
13	1		1	1	1	1	1			1	1		1			1			1		1	1		1
14	1	1		1		1	1	1		1	1	1	1		1	1			1		1	1		1
Total...	4	2	7	8	1	10	11	1		21	6	1	4		2	12			4		2	9		

Left eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								61
1	1		3			1	1			2				1	1	3	1					2		16
2	1		2	2		4	3			5	1		1			3	1				1	4		14
3	2		1			2				2						3						2		4
4	1	1		1																		1		1
5																								
6		1		1						1					1	1	1							1
11	2	2		2		1	1			2	1	1	1	1	1	2		1	1		1	2		2
12		2		2	1	2	2	1		2	1	1	1	1	1	1	1	1	1		1	2		2
Total...	7	6	6	8	1	10	7	1		14	3	2	3	3	4	13	4	2	2		3	13		

and light blue. The center skein in a number of instances was judged as more similar to the black skein on the left. Some subjects, although they admitted that they saw the center skein as dark or black, saw the lighter blue on the right and made their judgment conform to what they

thought it should be. They said, "Perhaps there is a little blue in the center one." No distinct cases of color blindness such as are found in the males were discovered at all among this group. One case rated as distinctly color-blind by the Ishihara Test made only one error on test I and two errors on test II. This case is obviously one in which there is

TABLE 11

Distribution of errors on the Nela Test for aged women. Test I

Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									42
1	9	1			1		3							4		1	1		3						23
2	8	4			3		2							3					2						11
3	4	2			2		1							3			2		1						5
4	2						1								1		1		1	1	1				2
5		1			1	1											1		1						1
6	1	1		1		1								1					1						1
Total...	24	9		1	7	2	7							11	1	1	5		9	1	1				

Left eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									46
1	5	2		1	3		1							4		1	2		2						21
2	6	1		4			3							1			1	1	1						9
3	2	1		1	1		2							1		1	1		1		1				4
4	2	2		1	2	1	1		1					2	1		1		1		1				4
5																									
6	1				1	1			1						1				1						1
Total...	16	6		7	7	2	7		2					8	2	2	5	1	6		2				

a central area not functioning in a completely normal way for color, but in which the rest of the retina is "normal."

Tables 13 to 16 inclusive present the data for group C. The types of errors made by this group, in general, are similar to those made by the other groups. In applying our standard of color blindness there appears a slightly higher percentage among the males. For test I, it is 9.3 per cent; for test II, 6 per cent. On the Ishihara Test, however, 13.6 per

cent of the males were diagnosed as color-blind. Four of the males rated as color-blind by the Nela Test were congenitally deaf. The cause and the age of onset of deafness of another individual was unknown. The last cases became deaf at 2, 3, and 12 years of age, with the causes unreported. The residual hearing in the color-blind males ranges from 0 to 40 per cent as tested by the 3A Audiometer.

TABLE 12

Distribution of errors on the Nela Test for aged women. Test II

Right eye

NUMBER OF ERRORS	TRIPLETS																						TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								44
1			3			7	2			6							1		1			5		25
2	1		1	2		3				5						1			1			4		9
3						2				2	1								2			2		3
4			1			1	1			2	1								2					2
5				1						1	1								1			1		1
6			1			1				1	1					1			1					1
Total...	1		6	3		14	3			17	4					2	1		8			12		

Left eye

NUMBER OF ERRORS	TRIPLETS																						TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								43
1			1	3		5	1			8					1				1			1		21
2			2	5		2	1			6	2			1		1			2			2		12
3				1		1				2	1					1			1			2		3
4	1		1	1		2	1			3	1		1			1			2		1	1		4
5				1		1				1	1								1					1
6				1		1	1			1									1			1		1
Total...	1		4	12		12	4			21	5		1	1	1	3			8		1	7		

The errors of the women in group C (given in tables 15 and 16) bear close resemblance to the usual forms found for the other groups. In testing this group we found that the girls grasped the problem more easily and in numerous instances went through the tests so rapidly that it was difficult to follow them. If color deficiencies are caused by or accompany any of the conditions to which deafness may be

attributed we should find more nearly equal numbers of cases among the females and among the males. In two cases of the women who

TABLE 13

Distribution of errors on the Nela Test for Gallaudet men. Test I

Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									27
1	4	1		1										3	1	1	3	1	1			1			17
2	5	1		1													3	4	2			2			9
3	1	1	1											1		1	2	2	1	1		1			4
4		1	1	2	1									2	1		2		1			1			3
5	1								3	1	2		2	2	4		1		2		2				4
6																									
7																									
8																									
10	1	1	1	1			1				1			1	1		1				1				1
13						1		1	1	1			1	1		1	1	1	1	1	1	1			1
Total...	12	5	3	5	1	1	1	1	4	2	3		3	10	7	3	13	8	8	2	4	6			

Left eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									32
1	2	1	3											2	2	3	3			1					17
2	1	1		1									2				4	1	1			1			6
3	1		1	1										2			1								2
4	1	1		1										2	1		2	1	2		1				3
5	1			1				2			1		1		2				1		1				2
6																									
7	1					1	1				1		1	2	1		2		1			1	1		2
8	1					1			1	1	1			1	1	1									1
16		1			1	1		1	1	1	1		1	1		1	1	1	1	1	1	1			1
Total...	8	4	4	4	1	3	1	3	2	2	4		5	10	7	5	13	3	6	2	3	3	1		

made errors deafness was congenital; in the other case the cause and the time of onset were unknown.

Although the percentage of defective color vision appearing in deaf males may indicate that in some cases the two sensory defects are

associated, the group is small and the percentage is not sufficiently large to provide an adequate basis for valid conclusions.

In tables 17 and 18 are given the total errors made on each triplet in tests I and II with both the right and left eyes. The frequency of

TABLE 14

Distribution of errors on the Nela Test for Gallaudet men. Test II

Right eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								32
1						1	1			6			1			2						2		13
2	1	2		1		3	1			2		1	1			3				1	3	3		11
3		1		1		1	1			2		1				2					1	2		4
4				1	1	1				1			1			1	1				1			2
5			1	1		1	1														1			1
6		1								1					1	1	1				1			1
13			1	1	1	1	1		1	1			1		1	1	1				1	1		1
20	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		1
Total...	2	4	3	5	3	9	6	1	2	14	1	3	5	1	3	11	4	1	1	1	9	9		

Left eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								35
1		1				1	2		3				1									4		12
2					1	1	1			4			1			4			1	1	3	1		9
3		1	1	1		1				2				1	1	2					1	1		4
4			1	1		1	1			1			1				1					1		2
5																								
6		1	1							1	1					1						1		1
7		1	1			1	1			1			1								1			1
13		1	2	1	1	2	1	2	2	2	2	1				1	1	1	1	1	2	2		2
Total...		5	6	3	2	7	6	2	5	11	3	1	4	1	1	8	2	1	2	2	7	10		

errors found in these tables provides a basis for the elimination of some of the triplets and shows that certain triplets are greater sources of error than others. Elimination of triplets should be governed not so much by the summated data on errors for all the groups as by the total errors of the individual groups.

Table 19 shows the relation of the results of the Ishihara Test to those of the Nela Test for all three groups. This table includes all cases in which the subjects made more than one error in the Ishihara Test. The numbers in parentheses indicate the total number of plates on which the subjects failed.

TABLE 15

Distribution of errors on the Nela Test for Gallaudet women. Test I

Right eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									25
1	3	1		1		1								1	2		6		1		1				17
2	2	2		2		2								3	2		3	1	1						9
3	1	3		3		1								2	2		2		1		3				6
4		2						1		1				1	1		2								2
5		1												1			1			1	1				
Total...	6	9		6		4		1		1				8	7		14	1	3	1	5				

Left eye

NUMBER OF ERRORS	TRIPLETS																							TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0																									24
1	5	1		1		1								4	1		5								18
2	2	2		1		2								2			2	1	1		1				7
3	1	2		3		3								2	2		1		2		2				6
4	1	1		2		1								2	2	1	1				1				3
5																									
6	1	2		2		1			1				1	1	1				1		1				2
Total...	10	8		9		8			1				1	11	6	1	9	1	4		5				

It can be seen that the males in group C instead of missing all the plates on the Ishihara Test, as we usually find, made a variety of errors. No adequate explanation can be offered for this difference.

The investigation of group D was initiated by the discovery of a case of acquired color blindness supposedly associated with diabetes. The case presented fairly conclusive proof that it was one of acquired defect because the individual had been subjected to repeated examination and had passed the color tests required for navigation licenses over a

considerable period of time. Investigation of this case showed that he could not read beyond the first plate in the Ishihara Test and made fourteen errors in test I of the Nela.

These results led us to test a group of diabetic retinitis patients in the Diabetic Clinic of the Johns Hopkins Hospital. Retinitis due to diabetes has been supposed by Parsons (51) usually to affect the per-

TABLE 16

Distribution of errors on the Nela Test for Gallaudet women. Test II

Right eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								26
1			1			2	2			3						1						3		12
2	1		1			2	2			5					1	2	1				1	2		9
3		1	1			3	2		1	3						2					2	3		6
4		1	1			1	1		1	2									1		2	2		3
5	1				1	1	2			2							1				1	1		2
6	1	1		1		1				2						2					2	2		2
Total...	3	3	4	1	1	10	9		2	17					1	7	2		1		8	13		

Left eye

NUMBER OF ERRORS	TRIPLETS																					TOTAL NUMBER OF CASES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
0																								24
1			1			4				3			2			1					1	2		15
2		1	1			1	3			5					1	2					1	3		9
3		1	2			3	2		1	4						3					2	3		7
4		1	1				1		1	3						1					2	2		3
5	1					1	1			1												1		1
6		1				1				1						1					1	1		1
Total...	1	4	5			10	7		2	17			2		1	8					7	12		

ception of red and green. In general, the ophthalmological investigations of the retina report scattered bright white spots around the macular region, punctate hemorrhages scattered over the fundus, and in some cases changes in the lens.

Although retinitis is a relatively rare complication of diabetes, we found seventeen cases listed in the clinic files. Of this number, only

eleven could be tested, the vision of the remaining cases having been affected by other complications. Of these eleven we found six men and four women who had definitely defective color vision. All the subjects had difficulty with the Ishihara Test and made more than eight errors of a consistent type on each part of the Nela Test. The one normal case found was a woman who had been diagnosed as having retinitis

TABLE 17

Total errors made on each triplet of all groups. Test I

		TRIPLETS																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23*
A	Men																							
	Right...	50	19	16	28	17	5			11	3	15	1	2	52	13	10	72	9	22	2	5	12	
	Left...	51	16	15	27	17	6			9	1	16		2	52	11	8	50	8	13	1	8	9	
	Women																							
	Right...	51	12	2	6	16	2	4	1	3	1		1		25	21	20	47	2	9		4		
	Left....	64	18	1	5	17	3	2	1	1	1		1		30	10	9	27		5		2	1	
B	Men																							
	Right...	24	11	4	18	6	1			1	1	4		1	15	7	5	16		6	1	5	1	
	Left....	16	10	6	13	4				3	1	4		3	14	2	4	16	3	10		3	5	
	Women																							
	Right..	24	9		1	7	2	7							11	1	1	5		9	1	1		
	Left....	16	6		7	7	2	7		2					8	2	2	5	1	6		2		
C	Men																							
	Right...	12	5	3	5	1	1	1	1	4	2	3		3	10	7	3	13	8	8	2	4	6	
	Left....	8	4	4	4	1	3	1	3	2	2	4		5	10	7	5	13	3	6	2	3	3	1
	Women																							
	Right...	6	9		6		4		1		1				8	7		14	1	3	1	5		
	Left....	10	8		9		8			1				1	11	6	1	9	1	4		5		
Total.....		332	129	51	129	93	37	22	7	37	13	46	3	17	246	94	68	287	36	101	10	47	37	1

* No error was recorded for triplet 24.

more than two years previous. Recent ophthalmoscopic reports on this subject indicate that the retina is clear, the hemorrhages having been almost completely absorbed.

In an effort to isolate some of the causal factors influencing possible change in color vision we retested the patients over a period of six months. Two, and in one case three, retests were secured on each of the group. Color vision of the women remained practically unchanged

on the retests. There was no opportunity to study the relation between color vision and blood-sugar level, since the patients could not be obtained when their blood-sugar changed.

Some of the men showed variations in color vision which seemed to be related to the blood-sugar level. When blood-sugar was normal color vision seemed better and vice versa. In one case in particular

TABLE 18

Total errors made on each triplet of all groups. Test II

		TRIPLETS																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22*
A	Men																						
	Right	14	12	17	21	5	38	26	3	1	54	12	3	10	3	3	36	3	2	1	6	14	40
	Left	8	17	19	30	3	24	17	2		57	7	4	9	4	6	44	8	2	2	2	16	42
	Women																						
	Right	1	3	18	8		23	18			46	4	2	2			7	2		11	2	10	44
	Left	2	1	22	15		23	23			48	4		3		2	6	3		7	2	5	42
B	Men																						
	Right	4	2	7	8	1	10	11	1		21	6	1	4		2	12			4		2	9
	Left	7	6	6	8	1	10	7	1		14	3	2	3	3	4	13	4	2	2		3	13
	Women																						
	Right	1		6	3		14	3			17	4					2	1		8			12
	Left	1		4	12		12	4			21	5		1	1	1	3			8		1	7
C	Men																						
	Right	2	4	3	5	3	9	6	1	2	14	1	3	5	1	3	11	4	1	1	1	9	9
	Left		5	6	3	2	7	6	2	5	11	3	1	4	1	1	8	2	1	2	2	7	10
	Women																						
	Right	3	3	4	1	1	10	9		2	17					1	7	2		1		8	13
	Left	1	4	5			10	7		2	17			2		1	8					7	12
Total		44	57	117	114	16	190	137	10	12	337	49	16	43	13	24	157	29	8	47	15	82	253

* No errors were recorded for triplet 23.

this was evident. None of the cases was able to complete the tests without errors, and these errors were consistently color-blind confusions.

Dashiell (9) noted in one case of diabetes that certain psycho-motor abilities varied with the blood-sugar level. His subject had difficulty in making decisions involving color-names and he inferred that the immediate effect of alterations of the blood-sugar level upon psychological efficiency is through changes produced in higher centers of the

TABLE 19

Showing relation of Ishihara and Nela Tests

WOMEN				SUBJECT NUMBER	MEN			
Test I		Test II			Test I		Test II	
Right eye	Left eye	Right eye	Left eye		Right eye	Left eye	Right eye	Left eye
				Group A				
2 (5)	1 (5)	0 (5)	3 (5)	1	4 (12)	4 (12)	2 (12)	2 (12)
2 (3)	0 (3)	0 (3)	1 (3)	2	5 (15)	4 (15)	1 (15)	3 (15)
2 (5)	1 (5)	0 (5)	3 (5)	3	2 (15)	2 (15)	4 (15)	4 (15)
8 (7)	6 (7)	5 (7)	6 (7)	4	8 (15)	8 (15)	10 (15)	10 (15)
				5	11 (15)	12 (15)	13 (15)	12 (15)
				6	14 (15)	14 (15)	12 (15)	13 (15)
				7	9 (15)	8 (15)	5 (15)	5 (15)
				8	12 (15)	12 (15)	9 (15)	10 (15)
				9	7 (15)	7 (15)	3 (15)	4 (15)
				10	14 (15)	14 (15)	13 (15)	12 (15)
				11	7 (15)	8 (15)	7 (15)	6 (15)
				12	5 (15)	4 (15)	1 (15)	3 (15)
				13	4 (4)	4 (2)	2 (4)	3 (2)
				14	6 (15)	3 (15)	1 (15)	1 (15)
				15	3 (15)	2 (15)	2 (15)	1 (15)
				16	2 (15)	2 (15)	4 (15)	2 (15)
				17	4 (15)	3 (15)	5 (15)	2 (15)
				18	2 (3)	3 (3)	1 (3)	1 (3)
				Group B				
1 (14)	1 (14)	3 (14)	3 (14)	1	11 (15)	12 (15)	14 (15)	12 (15)
				2	6 (15)	11 (15)	13 (15)	12 (15)
				3	12 (15)	12 (15)	5 (15)	6 (15)
				4	4 (15)	4 (15)	2 (15)	1 (15)
				5	12 (15)	11 (15)	11 (15)	11 (15)
				6	2 (5)	2 (6)	4 (5)	4 (6)
				7	1 (3)	2 (2)	2 (3)	1 (2)
				Group C				
1 (2)	1 (2)	1 (2)	1 (2)	1	5 (13)	7 (14)	5 (13)	7 (14)
0 (3)	0 (2)	1 (3)	0 (2)	2	5 (8)	5 (10)	3 (8)	2 (10)
				3	5 (13)	5 (14)	3 (13)	3 (14)
				4	10 (11)	7 (11)	6 (11)	6 (11)
				5	5 (9)	8 (8)	20 (9)	13 (8)
				6	13 (13)	13 (16)	13 (13)	13 (13)
				7	4 (15)	4 (15)	4 (15)	4 (15)
				8	2 (3)	1 (3)	2 (3)	1 (3)
				9	1 (3)	1 (3)	0 (3)	0 (3)

nervous system. To check the possibility that the color deficiency may be partly due to the effect of changes in blood-sugar level, we tested 16 patients with blood-sugar either below or above the normal level. In no case did we find any impairment of the color vision. It may be added that all of these cases were using insulin.

A recent retest of our original case of color deficiency with diabetes shows that this individual remains defective, confusing browns with reds and greens and showing other confusions typical of color-blind persons.

Although the evidence presented in this section does not offer any conclusive data concerning the rôle of diabetes in producing changes in color vision, it points out some of the problems of color vision that require further study. In so far as this investigation concerns the Nela Test, the method provides an adequate means for testing the deficiencies in this group. The Ishihara Test, because it involves visual acuity, was found to be difficult and of doubtful use in measuring color vision associated with pathological conditions of the eye.

SUMMARY

1. For the purpose of reducing the Nela Test, six triplets in test I (nos. 8, 10, 12, 20, 23, and 24) could be discarded. Possibly triplets 7 and 13 could also be discarded.

In test II, triplets 8, 9, 14, 18, 20, and 23 have shown no particular diagnostic value but should be evaluated on more color-blind subjects before they are definitely eliminated. Since triplet 1, test I, is similar to triplet 22, test II, it is possible that one of these may be eliminated.

2. The variety of applications to which this test has been put shows that the basic principle presents an adequate measure of color deficiencies. Numerical limits, however, should be established only after all sources of error other than hue confusions are eliminated from the test. The present arbitrary standard of more than four errors obviously includes some cases that cannot be exactly termed "color-blind." Of course, the question of the degree of color deficiency one must have in order to be classified as "color-blind" still remains a moot point. Since color vision, as has been pointed out earlier, probably has a "normal" distribution, any line drawn between "practically normal" and "color-blind" individuals will probably always be arbitrary.

3. Since certain triplets are obviously a greater source of error than others, these particular combinations should be presented to both color-blind and normal subjects to ascertain whether they are causing

confusion because of the brightness equality alone or whether the error is due to actual deficiencies of the color mechanisms.

4. From the results obtained in group B it appears that age *per se* has no deleterious effect on color vision.

5. Although the percentage of color-blind among deaf persons is slightly higher than among normal individuals, we cannot say at the present time that a defect in one sensory mechanism is accompanied by a defect in another sensory mechanism. It is certain, however, that the Nela Test presents a situation that is sufficiently simple and applicable to individuals included in the deaf group.

6. The investigation of the group having color deficiencies accompanying diabetic retinitis, although not solving any of the diverse problems of acquired color defect, does indicate that changes in metabolism may be responsible for alteration in color perception.

BIBLIOGRAPHY

(1) Abney, W. de W.: Color Blindness. William Wood & Company, New York, 1895.

(2) Bell, Julia: The Treasury of Human Inheritance, Nettleship Memorial Volume. Part II, Color Blindness.

(3) Brunner, W.: Graefe's Arch. f. Ophth., 1930, **124**, 1.

(4) Carter, R. B.: Color vision. Rept. Smithsonian Institute, 1890, **1**, 687.

(5) Chance, Burton: Monochromatic vision. Amer. Jour. Ophthalmol., **14**, no. 5, 417.

(6) Clements, F.: Comparative racial differences in color blindness. Science, 1930, **72**, 203.

(7) Collins, Mary: Colour Blindness. Harcourt Brace & Company, 1925.

(8) Cowdrick, M., and Winfield, M.: The adjustment of the Hering color-blindness apparatus. Amer. Jour. Psychol., 1919, **30**, 418.

(9) Dashiell, J. F.: Variations in psycho-motor efficiency in a diabetic with changes in blood-sugar level. Jour. Comp. Psychol., 1930, **10**, no. 2, 189.

(10) Donders, F. C.: Farbengleichungen. Archiv. f. d. g. Physiol., Leipzig, 1884.

(11) Donders, F. C.: Die quantitative Bestimmung des Farbenunterscheidungsvermogen. Graefe's Arch. f. Ophth., 1877, **23**, 282.

(12) Donders, F. C.: Oculistique. Ann. d'ocul., 1880, **34**, 212.

(13) Dor, H.: Eschelle pour mesurer l'acuite de la vision chromatic. Paris, 1878.

(14) Downey, June E.: Three generations of color blindness. Jour. Gen. Psychol., **5**, no. 4, 459.

(15) Dunlop, J. C., and Mackay, G.: The cerebral lesions in a case of complete acquired color blindness. Scot. Med. and Surg. Jour., **5**, 502.

(16) Everbusch, O.: Ein Apparat zur praktischen Untersuchung des Farbensinnes beim eisenbahn und marine Personal. Graefe's Arch. f. Ophth., 1900, **50**, 151.

(17) Ferree and Rand: An instrument for testing the light and color sense with important features of standardization and control. Amer. Jour. Psychol., 1931, **43**, 275.
(18) Fry, W. E.: Report of a case of total color blindness. Amer. Jour. Ophthalmol., 1931, **14**, 56.
(19) Garth, Thomas R.: The incidence of color blindness among races. Science, 1932, **77**, 333.
(20) Geldard, F.: Report of a case of total color blindness. Unpublished; read before the Southern Society for Philosophy and Psychology, April, 1933.
(21) Edridge-Green, F. W.: Color Blindness and Color Perception. Kegan Paul, Trench, Tribner & Company, London, 1909.
(22) Edridge-Green, F. W.: Card test for color blindness. Proc. Roy. Soc. Med., Sec. Ophthalmol. 1920, **13**, 62.
(23) Edridge-Green, F. W.: Detection of color blindness from a practical point of view. Amer. Jour. Ophthalmol., 1931, **14**, 152.
(23a) Edridge-Green, F. W.: The Physiology of Vision: With Special Reference to Color Blindness. G. Bell & Sons, London, 1920.
(24) Grossman, K.: Color blindness with demonstration of new tests. Brit. Med. Jour., 1888, **2**, 1041.
(25) Guttmann, A.: Untersuchungen Farbenschwache. Ztschr. f. Sinnesphysiol., 1907, **42**, 24.
(26) Haupt, I.: Nela Test for Color Blindness applied to school children. Jour. Comp. Psychol., 1926, **6**, no. 4, 291.
(27) Haupt, I.: Test for color blindness. A survey of the literature with bibliography to 1928. Jour. Gen. Psychol., 1930, **3**, no. 2, 222.
(28) Hering, E.: Zur Diagnostik der Farbenblendheit. Arch. f. Ophth., 1890, **36**, 217.
(29) Hering, E.: Zur Lehre von Lichtsinne. Wien, 1878.
(30) Ishihara: Test for Color Blindness. Stoetling & Company, Chicago.
(31) Jennings, J. Ellis: Evaluation of pseudo-isochromatic tests for the detection of color blindness. Amer. Jour. Ophthalmol., 1931, **14**.
(32) Kirschman, A.: Beitrage zur Kenntniss der Farbenblindheit. Philosophische Studien, Bd. VIII, Leipzig, 1893.
(33) Konig: Litzungen der Akademie der Wissenschaft, 1897.
(34) Kolbe, B.: Beitrage zur quantitativen und qualitativen Prufung des Farbensinnes. Arch. f. Augenh., 1883, **13**, 53.
(35) Kries, von: Nagel's Handbuch der Physiologie des Menschen, 1905, vol. 3.
(36) Landolt, E.: Procede pour determination de la perception des couleurs. Ann. d'ocul., 1877.
(37) Larsen, H.: Demonstration mikroskopischer Praparate von einen monochromatischen Auge. Ztschr. f. Augenh., Berlin, 1921, **46**, 228.
(38) Lediard, H. A.: Color test for railroad purposes. Lancet, 1889, 1056.
(39) Lenz, G.: Zwei Sektiensfalle dappelsertiger zentralen Farbenhemianopsie. Ztschr. f. d. ges. Neurol. u. Psychiat., Berlin, 1921, **71**, 135.
(40) Mackay, G., and Dunlop, J. C.: The cerebral lesions in a case of complete acquired color blindness. Scot. Med. and Surg. Jour., **5**, 502.
(41) Miles, W., and Craig, H., Jr.: Color blindness in dry goods salesmen. Personnel Jour., 1931, **9**, 437.

(42) Miles, W.: One hundred cases of color blindness detected with the Ishihara Test. Jour. Gen. Psychol., 1929, **2**, no. 4, 535.
(43) Nagel, W.: Tafeln zur Untersuchung des Farbenunterscheidungsvermogen. Wiesbaden, 1906.
(44) Nagel, W.: Zwei Apparate fur die augenargtliche Functionsprufung. Ztschr. f. Augenh., 1907, Hefte 3, 216.
(45) Nettleship, E.: Note on some varieties of albinism. Trans. Ophth. Soc. United Kingdom, London, 1906, **26**, 244.
(46) Nettleship, E.: Some unusual pedigrees of color blindness. Trans. Ophth. Soc. United Kingdom, London, 1912, **32**.
(47) Oguchi, C.: Zur Kenntniss der Farbensinnes und seiner Storungen. Arch. f. Augenh., 1914, **77**, 205.
(48) Parinaud, H.: The sensitivity of the eye to colors of the spectrum. Jour. Ophthalmol., Otol., and Laryngol., 1896, **8**, 51.
(49) Parsons, J. H.: An Introduction to the Study of Color Vision. Cambridge, Mass., Cambridge Press, 1924.
(50) Parsons, J. H.: Color vision and its anomalies. Brit. Jour. Ophthalmol., 1930, **14**, 97.
(51) Parsons, J. H.: Diseases of the Eye. Macmillan, 1930, 6th edition.
(52) Pole, W.: Color blindness. Nature, 1879.
(53) Preston, F. E.: Report to Royal Society of Medicine, Society on Ophthalmology. Amer. Jour. Ophthalmol., 1931, **14**, 546.
(54) Rayleigh: Color equations. Nature, 1881, **25**, no. 2, 64.
(55) Rivers, W. H. R.: Observations on the senses of the Todas. Brit. Jour. Psychol., 1905, **1**, 321.
(56) Richardson, F.: An unusual case of color blindness. Amer. Jour. Psychol., 1923, **34**.
(57) Rivers, W. H. R.: Vision. Shafer's Text Book of Physiology, 1900, **2**.
(57a) Sacks, E.: Contributors to the heredity of disturbances of color sense. Klin. Monatsbl. f. Augenh., 1928, **81**, 231.
(58) Scarlett, H. W.: Senile macular changes of the retina associated with focal infection. Amer. Jour. Ophthalmol., 1931, **4**, 932.
(59) Scripture, E. W.: The color sense tester. Yale Univ. Studies in Psychol., 1900, **8**, 1.
(60) Seebeck, A.: Ueber den bei manchen Persenen vorkommenden Mangel an Farbensinn. Poggendorff's Ann. der Physik un a chemie, 1837.
(61) Stilling, J.: Ueber Enstehung und Wesen der Anomalien des Farbensinnes. Ztschr. f. Sinnesphysiol., 1910.
(62) Stilling, J.: Pseudoisochromatische. Tapeln, Leipzig, 1883.
(63) Soriano, F. J.: Diagnostic de la cecite de couleurs. Clin. opht., 1928, **17**, 319.
(64) Snellen, H.: La determination quantitative due sens chromatique. Nederl. tijdschr. v. geneesk., 1897, **33**, 688.
(65) Terman, S. W.: A new classification of red-green color blindness. Amer. Jour. Psychol., 1929, **41**, 333.
(66) Usher, C. H.: Histological examination of an adult albino's eyeball. Biometrika, Cambridge, 1921, 13.
(67) Vogt, A.: Rev. gén. d'opht., 1922, **36**, 312.

(68) Waalen, G. H. M.: The hereditary characteristics of different forms of congenital red-green blindness. Acta ophth., 1927, **5**, no. 5, 309.
(69) Waardenburg, P. J.: Ein Geval van vollieize Kleurenblindheit. Nederl. tijdschr. v. geneesk., 1924, **68**.
(70) Wolfflin, E.: Ueber angeborne totale Farbenblindheit. Klin. Monatsbl. f. Augenh., 1924, **72**.
(71) Weber, A.: Apparat zur numerischen Prufung des Farbensinnes. Klin. Monatsbl. f. Augenh., 1878, **16**.
(72) Williams, C. H.: The need of a supplementary lantern test. Boston Med. and Surg. Jour., 1903.
(73) Wilson, G.: Researches on Color Blindness. Edinburgh, 1855.
(74) Winfield, M., and Cowdrick, M.: The adjustment of the Hering color-blindness apparatus. Amer. Jour. Psychol., 1919, **30**, 418.

VITA

Vernon Philip Scheidt was born January 2, 1906, in Baltimore, Maryland. He received his elementary and secondary education in the public schools of that city and the degree of Bachelor of Arts from St. John's College at Annapolis, Maryland, in 1929. In the autumn of 1929 he enrolled as a graduate student in the Department of Psychology at The Johns Hopkins University. He was student assistant in the Department of Psychology, 1932–1933.